INVISIBLE LIGHT

By FRITZ SCHAALE

On March 27 the world will celebrate the hundredth birthday of Wilhelm Konrad Röntgen, the man who discovered X rays—or Röntgen rays—in 1895 and thereby became a benefactor of mankind. In commemoration of this event we shall not describe his life, which was the uneventful life of a scientist; instead, we shall discuss the problem of radiation and the place taken by Röntgen rays in radiation. The author may be recalled by our readers from his article "Stars and Atoms" (January 1945) as a physicist who can express complicated matters in simple words.

OUR sensation of light has no resemblance to that which really takes place between our eyes and the sun or the lamps emitting that light, just as our sensation of sound is quite different from the sound waves coming from the body giving forth this sound. Hence to the physicist light is not the sensation but the process of transmission which, as in the case of sound, is a propagation by waves. But while sound waves consist of condensations and rarefications of the air, every body emitting light is a transmitter of electric waves of the same type as radio waves; this is not to be taken figuratively: it is actually the case. This does not explain the essence either of light or of radio waves; it merely establishes the identical nature of both phenomena. They are related to each other in the same way as sounds of a high and low pitch: they merely differ in their wave lengths. But while the ratio between the wave lengths of the highest and lowest sounds is about 1 : 1,000, the ratio between the wave lengths of light and of radio waves is about 1 : 1,000,000,000.

Any vibrating body, for example, the pendulum of a clock, causes condensations and rarefications of the air which spread in an undulatory motion in all directions. But only if the number of these vibrations is between 30 and 20,000 per second do we perceive them as sound; the very slow and very fast vibrations beyond this range merely lack the property of affecting our auditory nerves. However, this does not indicate any physical difference in the vibrations or waves but simply characterizes a peculiarity of the human sense of hearing. In the same way, our eye is a receiver for electric waves which can only be tuned to a limited range of wave lengths, viz., a few 10,000ths of a millimeter. As the longest visible waves are twice as long as the shortest visible waves, one can speak of this range as of an octave, since the wave lengths of two sounds an octave apart differ in the same proportion.

Now every glowing body radiates innumerable electric waves of various lengths of which sometimes only a very small proportion are within the visible range. The proportion is particularly great in the case of the radiation of the sun, i.e., 46 per cent. We repeat, this visible sunlight differs from invisible sunlight only in our eyes; for the rest of our body as well as for most other objects it only represents heat, and now and again it shows some other effects, viz., fluorescence, phosphorescence, and the effect on photographic plates and on the photoelectric cells in exposure meters. In the invisible part of sunlight, 41 per cent is long-wave infrared and 13 per cent short-wave ultraviolet light. These terms arose from the fact that, in the visible light, red possesses the longest and violet the shortest wave length. Apart from the effect on the retina of our eye, this invisible light produces the same effect when it strikes our body as the visible, only to a differing degree. The heat effect of infrared light can be shown by means of a thermoelement; it is also possible to photograph in the infrared range with the aid of special films. Ultraviolet light also has a heat effect, but as it is usually not very strong it is easier to show its presence by means of photography and the photoelectric cell.

Very interesting is the behavior of transparent substances toward these invisible rays. Thus ordinary glass is for both types almost entirely opaque, as is air for ultraviolet light when the wave length is less than half the wave length of violet light. On the other hand, infrared light is not scattered like ordinary light by tiny particles of mist; hence it is possible to photograph through mist and fog with films sensitive to ultrared. One substance that is transparent to a very wide range, especially in the ultraviolet sector, is quartz. "Uviol" glass appears almost opaque to the eye but allows ultraviolet light to pass through. The possibility of transmitting secret messages by infrared light is based on similar qualities: by means of attaching and detaching filters, blinking signals can be given while the visible light remains unchanged.

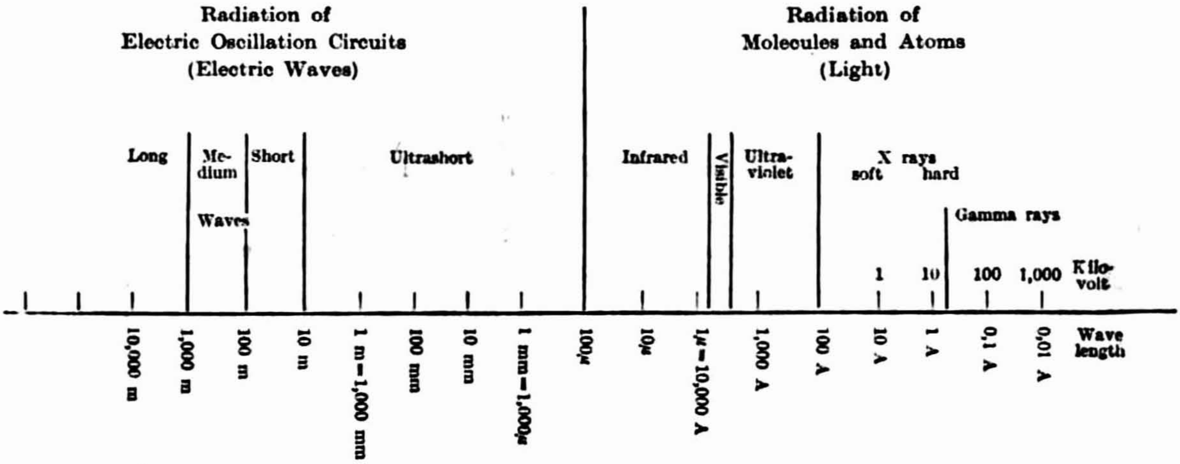
Our electric bulbs radiate less than 10 per cent visible light, the remainder being almost exclusively infrared. The difference from sun radiation consists in their temperature being only 2,000° centigrade, while that of the sun is 6,000°. For, according to the law discovered by Max Planck in 1900, not only does the total force of radiation increase considerably with rising temperature, but also the proportion of short-wave light. The radiation of a stove consists entirely or almost entirely of very long-wave infrared light, many "octaves" below the visible; not until the temperature rises to 600° does the proportion of visible light of the greatest wave length become noticeable: we notice a slight red glow, but also a strong radiation of heat. The light radiated by electric bulbs at 2,000° is considerably whiter, as there is also a noticeable proportion of visible light of shorter wave lengths. At the sun's temperature of 6,000° the proportion of visible light in the total radiation is greatest, and it decreases at higher temperatures in favor of ultraviolet light. However, this does not mean that hotter stars would appear darker, for the absolute amount of visible as well as all other light increases with the temperature, only the proportions changing.

The hottest stars have a surface temperature of 20,000°, as can be told from the distribution of the various types of light in their radiation. The difference between their temperature and that of the sun is not great enough to endow their radiation with an essentially different character. Conditions are different in the interior of the stars, where there must be temperatures of several million degrees. Here by far the largest part of radiation consists of Röntgen light, whose wave length is 1/1,000th of that of ordinary light. Moreover, this radiation exerts, as the result of its unimaginably greater total intensity, a direct mechanical pressure, which can be ignored in all terrestrial processes but which in the stars themselves amounts to several thousand atmospheres, combining with the pressure of elastic material to counteract gravity and thus preventing the star contracting to a minimum size.

It is only because the necessary temperatures cannot be achieved that the extremely short-wave Röntgen light cannot be produced as heat radiation in terrestrial laboratories. Even visible light can, however, be obtained by other means than heating a substance. Cold light has long been known in the forms of fluorescence and phosphorescence. They can be produced by irradiation with light of short wave length, as in the case of luminous dials, as well as by the cathode rays discovered by Hittorf in 1869. These latter consist of particles charged with negative electricity (electrons) which are forced by means of a high-voltage current out of a metal cathode and which move at great speed, a speed they maintain in a rarefied atmosphere. It is these particles which transport the electricity through a radio tube. Heating the cathode increases the number of electrons issuing forth, but their speed is determined entirely by the electric tension. In a highly exhausted tube their path can no longer be discerned; instead, at the point where they impinge upon the opposite glass wall a green fluorescent light appears. Electrons moving at high velocity also produce an invisible short-wave light, and if the tension of the electric current is raised to more than 1,000 volts their velocity becomes great enough to produce X rays. For the greater the tension and consequently the velocity of the electrons, the shorter does the wave length become of the light produced by the impact. It has been found more effective to let the electrons strike not on glass but on metal, especially platinum or tungsten, as thereby a greater power of radiation is achieved.

Röntgen's X rays can be observed in the same way as ultraviolet rays, even more easily, since they usually surpass the latter in effectiveness. Their fluorescence and photographic effect is known to anyone who has ever been in an X-ray laboratory. In addition to this, they are able to render air electrically conductive and possess a strong light-electric effect by forcing high-speed electrons out of metal surfaces. After what we have learned about the transparency of various substances to infrared and ultraviolet light, the penetrating power of the X rays will no longer amaze us. It was this quality by which it first betrayed itself to the physicists Röntgen and Lenard in 1895: it annoyed them by spoiling photographic plates still in their packing, while the scientists were studying the penetration of cathode rays through various substances.

It is remarkable, however, that no substance is as transparent to X rays as glass is to visible light: they are considerably weakened by every known substance. The reasons for this are, on the one hand, scattering such as visible light undergoes on the surface of most bodies and in semiopaque substances like milk, fog, or smoke; and on the other, absorption, the X rays being transformed into fluorescence radiation of longer wave length—which sometimes becomes visible—or into electron radiation, heat, or chemical reactions. It is the scattering of visible light on the various parts of the bodies which makes most objects visible to us and prevents our seeing through them; for the much smaller wave lengths of the X rays, even the molecules and atoms, are too big to produce this effect. With respect to this slight degree of scattering, all types of X rays are identical; on the other hand, the longer waves are generally more readily absorbed than the shorter ones. Hence increasing the tension in the X-ray tube, with the ensuing shortening of the wave length, results in "harder" rays. Very "soft," i.e., long-wave X rays are even absorbed by the air. Substances of great density and a high atomic weight, i.e., metals, particularly lead, show the greatest opacity to X rays, so that



lead is used to screen off the rays. The higher atomic weight of the calcium in the bones as compared to the atoms in the other parts of the body explains why the bones show up so well in an X-ray photograph. It is also well known that the stomach and other cavities are filled with a barium or bismuth preparation, both metals of high atomic weight, to make these organs visible. In order to discover hidden flaws in the interior of metals, very "hard" rays are required, which are produced by tensions of several 100,000 volts.

Unfortunately, only shadow outlines can be produced and not clear images shown as in the visible field by means of lenses in cameras, microscopes, etc. This possibility is based on light refraction and hence on the differing speeds of light in various transparent substances. But the speed of X rays in all substances is more or less the same as the speed of light in a vacuum, so that there is no refraction and reflection and hence no lenses and mirrors for Röntgen light.

Laue observed some peculiar phenomena in 1912. When X rays pass through crystals, he found, the regularly arranged atoms do not diffuse the rays in all directions but only in certain ones, depending on the arrangement of the atoms and the wave length. This phenomenon corresponds to the diffraction of visible light on an optical grid. In both cases we are able thereby to determine the wave length.

An extended exposure to X rays is always harmful to the human organism. Those people who have constantly to work with X rays must protect themselves with lead screens, and for medical purposes the strength and hardness of the rays as well as the period of application must be dosed accurately. The tension and power of the current in the tube are alone responsible for the strength of the rays, while the hardness can be regulated by the tension as well as by the employment of suitable filters. By this means it is possible to hold back the soft rays, which are particularly dangerous because of their quality of being easily absorbed. Knowing how various wave lengths are absorbed by various substances, we can, without any considerable loss, filter out limited ranges of Röntgen light.

The shortest waves, corresponding to an electric tension of 100,000 volts, appear in nature as the gamma rays of radioactive substances. These short wave lengths cannot be measured by diffusion in crystals, as the spaces between the atoms are too large; they can only be measured by their penetrating power. So here we meet with rays again which, like the ultrared, the visible, and the ultraviolet rays, do not owe their existence to human activities, while the X rays, which fill the wide gap between the ultraviolet and the gamma rays, are for their major part the work of man, at least as far as they appear on the surface of the earth.

The Tiara

Prince Metternich's second wife was very clever, but not as diplomatic as the position of her husband required. One day when the Ambassador of Louis Philippe, the bourgeois king who succeeded to the French throne after the Revolution of 1830, wished to pay her a compliment by admiring the beauty of her tiara, the Princess replied: "At least it's not a stolen one, like that of some kings!"

The French Ambassador complained to Metternich about this veiled aspersion. The latter, however, replied with mild dignity: "My dear Duke, I fell in love with my wife, I married her, but I did not educate her."